The Eelgrass *Zostera capricorni* in Illawarra Lake, New South Wales

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Zostera capricorni Aschers. is the dominant angiosperm in Illawarra Lake where it occurs over a wide range of substrate types (14-98% sand, 0.5-12% organic carbon) and salinity (3 ‰ — normal seawater). Distribution and abundance are related to light availability. The growth cycle shows a maximum in summer, with a winter minimum following shedding of the previous season's growth. Flowering is extensive but even though seedlings have been observed, propagation appears to be almost entirely vegetative. *Zostera,* complete with substrate, has been successfully transplanted.

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Introduction

Illawarra Lake is a coastal saline lagoon which straddles the boundary of the city of Wollongong (34°30'S, 150°50'E) in the north, and the Shellharbour municipality in the south, Fig. 1. The lake has evolved from a broad bay by the formation of a baymouth sand bar (Thom, 1974).

Lakes formed in this way tend to be broad, shallow, exposed and turbulent expanses of water with an extensive sandy zone supporting benthic macrophytes. Illawarra Lake is no exception. It has a maximum length of approximately 9.5 km and a width of 5.5 km with an approximate area of 33 km². The lake is shallow; an estimated 25% is less than 1.2 m deep and the maximum depth is only 3.7 m (Roy and Peat, 1973). The lake is oriented N-S parallel with the coast and is thus exposed to strong southerly and south westerly winds; lake water can be turbulent with wave heights approaching 0.5 m (Eliot *et al.,* 1976). This turbulence coupled with the shallow nature of the lake causes considerable turbidity and is probably a significant factor in maintaining the concentration of dissolved oxygen (Kanamori, 1976).

At present the lake enters the ocean near the southern end of the sand barrier where it is partially protected by Windang Island. This rocky prominence, which is usually land-tied by a tombola, dissipates wave energy and thus suppresses the rate of infilling of the entrance channel. The present channel from the lake to the ocean changes continually in position, width and depth depending on factors such as rainfall, wind and wave action. During 1972-1977 the entrance channel has been about 2.5 km long, winding and varying in depth up to 2.5 m. The main channel is seldom more than 100 m wide. It is restricted by a sand bar at the Windang bridge and occasionally the bar has completely choked the entrance. In late 1971 a blocking bar formed and this was subsequently cleared with earthmoving equipment. As a consequence of the restricted access to the sea very little tidal influence extends into the lake even at spring tides. Eliot *et al.* (1976) report a tidal rise of up to 0.1 m (cf. 2.0 m on the nearby ocean coast) on the western side of the lake at the Tallawarra power station. Ellis *et al.* (1977) estimate a tidal volume of 1% of the lake volume.

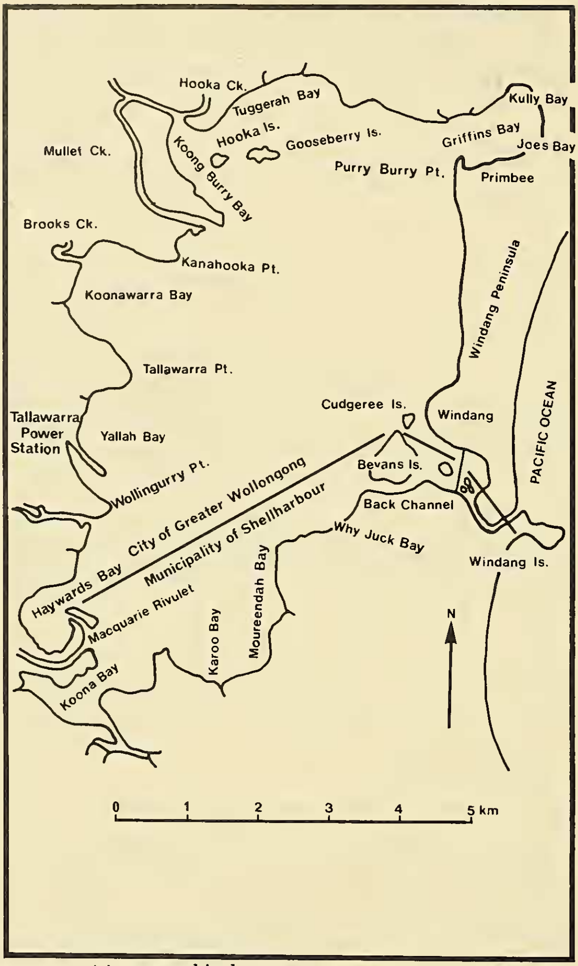

Fig. 1. Map of Illawarra Lake with geographical names

THE FLORA OF ILLAWARRA LAKE

Zostera capricorni Aschers. is the only seagrass recorded for Illawarra Lake and its distribution and abundance are the main subject of this paper. The range of morphology exhibited by *Z. capricorni* in Illawarra Lake is considerably greater than that given by Den Hartog (1970). *Ruppia* sp. is the only other angiosperm abundant in the benthic flora: it occupies approximately 30% of the eastern weed beds as a dense meadow in water 40-60 cm deep, Fig. 2. In shallow areas growth is reduced to sparse clumps. The change to *Zostera* with deeper water is abrupt. Isolated patches of *Ruppia* occur throughout the lake and in Hooka Creek, over a salinity range of 3-32 ‰. At all localities *Ruppia* grows inshore of *Zostera*, the reverse of the situation outlined by Higginson (1965) in the Tuggerah Lake system. Higginson suggested that *Ruppia* tended to favour clayey sediments, cf. *Zostera* on sandy sediments, but this conclusion was not borne out in this study. Wood (1959a) and Higginson (1965) both concluded that *Ruppia* is intolerant of strong currents and occurs mainly in sheltered bays. In this case high turbulence in Illawarra Lake may be the limiting factor for *Ruppia* which is then confined to the sheltered localities inshore of *Zostera*.

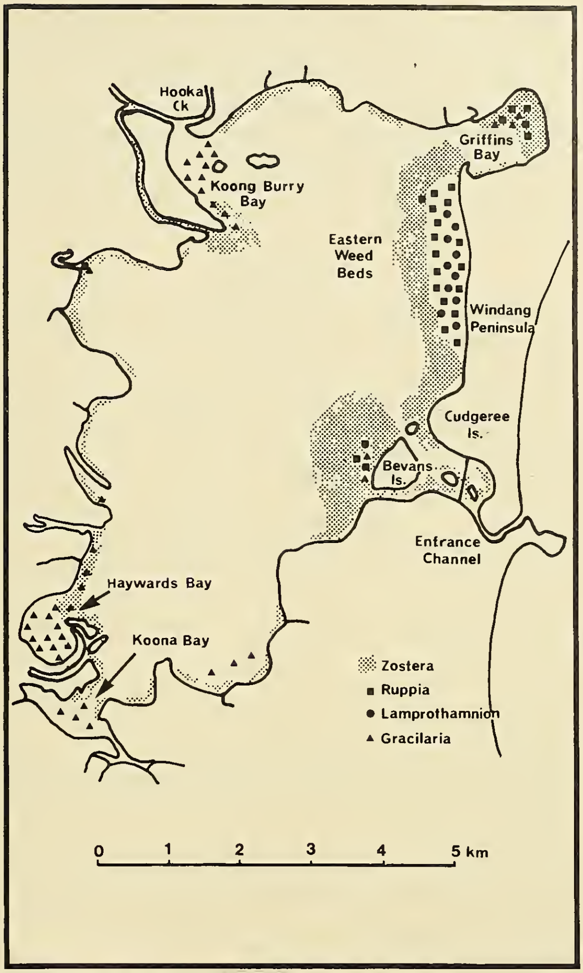

Fig. 2. Distribution of benthic plants in Illawarra Lake

Posidonia australis Hooker is not recorded in Illawarra Lake though the reasons for its absence remain obscure. *Posidonia* is reported to be intolerant of strong currents and turbulence (Wood 1959a, b; Den Hartog, 1970) and also appears to be intolerant of high turbidity. High turbidity may prevent growth of *Posidonia* in the body of the lake but could not account for its absence in the entrance channel area. Turbulence and current velocities in the channel area do not approach the rip conditions observed in the entrance to Macquarie Lake where Wood (1959a) reports growth of *Posidonia*.

Halophila ovalis (R. Brown) Hooker was also surprisingly absent from Illawarra Lake. It occurs along the N.S.W. coast on a wide range of sediment types encompassing those found in Illawarra Lake, and over a wide range of conditions of salinity and turbidity. Despite its apparent wide ecological tolerance *Halophila* has not been observed in Illawarra Lake.

Macroalgae were common in the Lake, particularly as epiphytes on *Zostera* and *Ruppia*. The most conspicuous were *Polysiphonia* sp., *Enteromorpha intestinalis* (L.) Link and *Cladophora* sp.; the latter species generally occurring in spring and early summer. The *Enteromorpha* and *Cladophora* form extensive floating mats in protected bays and in the inshore parts of the eastern weed beds. The benthic alga *Gracilaria verrucosa* (Huds.) Pap. occurred throughout the year and the broad distribution is shown in Fig. 2. In the southern bays, Koona and Haywards Bays, it was the dominant species occupying the silty sediments in the central portion of the bays. At least in initial stages plants are attached to the sediment. *Lamprothamnion* was variable in occurrence but mainly associated with *Ruppia* inshore of *Zostera* in the eastern weed beds, Fig. 2.

Methods

The data and observations presented in this paper were gathered over the period 1971-1976. Complete details can be obtained from Harris (1977). The data include: observations on the distribution and abundance of *Zostera capricorni* and other components of the benthic flora including epiphytes; details of the relationship between *Zostera* distribution, biomass and environmental data; long term observations on growth and flowering in *Zostera*.

In the analysis of sediments and water quality the following techniques were used:

Particle size analyses were conducted according to Folk (1968).

Organic carbon was estimated from loss on ignition at 550°C as described by Dean (1974).

Total phosphorus was determined colorimetrically using the single solution method detailed in Major *et al.* (1972).

pH was measured using a specific ion meter and pH combination electrode (*Orion Model 407A* and *electrode no. 91-02*). Sediment pH is based on interstitial water extracted from the sediment by pressure.

Eh was measured using an Eh combination electrode (Orion no. 96-78) standardized using Zo Bel solutions as described by Whitfield (1971). Sediment Eh was made on carefully mixed samples.

Salinity was measured as chlorinity using a chloride electrode (Orion no. 96-17).

Temperature was measured using a standard 50°C mercury thermometer.

Turbidity measurements were initially made with a secchi disc but later using a turbidimeter (*Hach Model 2100A*).

Wherever possible data from other sources, particularly Ellis and co-workers, were used.

Results and Discussion

I Distribution of *Zostera* in Illawarra Lake in relation to environmental factors

The major development of *Zostera capricorni* occurred in the eastern portion of the lake, and particularly off the Windang Peninsula and west of Bevans Island, Fig. 2. A narrow fringing zone seldom more than 20 m wide occurred around most of the bays in the western portion, except where *Gracilaria* was dominant.

(A) Sediment Factors. The composition of sediments supporting *Zostera* is given in Table 1. Extreme ranges were: particle size, sand 52 to 98%; organic carbon 0.5 to 8.5%; total phosphorus 35 to 120 $\mu g.g^{-1}$. Even greater extremes in values for particle size and organic carbon relate to the single site in Hooka Creek: 14% sand and 12% organic carbon. pH and Eh measurements were restricted to the eastern sandy portion of the Lake. Sediment pH ranged from 7.4 to 8.0 and Eh from +10 to −185 mV. This range of sediments, together with the lack of relationship between the distribution of sediment types in Illawarra Lake and the distribution of *Zostera* suggest that *Zostera* is not limited by sediment type.

TABLE 1

Composition of sediments supporting *Zostera* in Illawarra Lake
Mean values: range given in parentheses

Location	Number of samples	Sand %	Organic carbon %	Total phosphorus μg.l^{-1}
Griffins Bay	12	90 (77-97)	2.3 (0.8-3.5)	82 (35-105)
Eastern Weedbeds (off Windang Pens.)	8	96 (95-97)	1.5 (0.5-2.7)	61 (39-111)
Bevans Island	18	92 (88-97)	1.8 (0.8-4.3)	72 (53-120)
Southern Bays	5	82 (52-97)	3.3 (1.3-8.5)	—
Western Weedbeds	5	84 (58-92)	3.3 (2.1-5.2)	—
Hooka Creek	1	14	12.0	—

Where the reduction of *Zostera* beds occurred in Koona Bay and Koong Burry Bay over the period 1972 to 1977 it appeared to be related to rapid accretion of sediments. In other places in the lake (e.g. the northern side of the entrance channel east of the Windang Bridge, on the delta at the lake end of the entrance channel, in the shallows to the north of Cudgeree Island and the delta of the Griffins Bay tank trap) burial and subsequent recovery has been a frequent occurrence.

(B) Water Factors. Water quality in Illawarra Lake was highly variable. This is partially due to the fluctuating level of the lake: records of the N.S.W. Electricity Commission (1971) show an average variation in lake level of about 60cm in the period 1966-70.

Salinity. Ellis *et al.* (1977) showed that mean salinity in the Lake is controlled primarily by rainfall, and varied from 12.8 to 31.3 ‰ during a two year monitoring period. There was essentially no salinity stratification, with vertical mixing by wave action completed within 2-4 weeks. There was no significant east-west salinity gradient even though the major creeks are on the western side of the lake.

Zostera grew and even flowered over a wide range of salinity, from approximately 3 ‰ in Hooka Creek to approximately 35 ‰ in the entrance channel. This is outside the range experienced in the lake and it was concluded that salinity did not limit *Zostera* distribution.

Temperature. Ellis and Kanamori (1977) record a mean water temperature for Illawarra Lake in the range 11.6 to 25.6°C. In the Tallawarra Power Station outlet channel, water temperatures at times exceeded 35°C yet *Zostera* persisted at this site. It is concluded that water temperature was not a limiting factor since the differences in temperature between various sites on the lake was always slight, usually less than 3°C, and new growth was observed throughout the year.

Phosphorus. The nutrient status of the lake water, with regard to phosphates was generally beyond the level of enrichment needed to promote algal blooms (Anon., 1975; Wetzel, 1975). The observed total phosphorus range was 4 to 145 μg P.l^{-1} (Kanamori, 1976). Because the lake was turbulent and the phosphate level of the sediment high, localized deficiencies in water phosphorus concentrations would be quickly restored by water circulation and by disturbance of the sediment. It is thus unlikely that the distribution would be limited by phosphorus deficiency.

Some very high concentrations of total phosphorus, up to 3,600 μg.l^{-1} were observed in small creeks draining from non-sewered urban areas. Associated with this was a high *E. coli* count indicating that much of the nutrient inflow to Illawarra Lake is derived from domestic effluents and sewage. In areas adjacent to some streams, and in some bays, notably near Albion Creek in Koona Bay, in Kully Bay and Joes Bay

(Griffin Bay), Why Juck Bay, and in the Back Channel, *Zostera* grew sparsely or not at all. In these areas the green alga *Enteromorpha* grew in large floating masses shading the *Zostera*. In this way excessive phosphorus levels may have been indirectly responsible for restricting the distribution of *Zostera*.

Nitrate levels in the Lake have a mean value of 2 $\mu g.l^{-1}$ (Kanamori, 1976) which is lower than values reported by Higginson (1971) for Tuggerah Lakes or Spencer (1959) for Macquarie Lake.

pH and Eh. The observed ranges of pH and Eh for lake water were narrow; pH 8 to 8.4 and Eh +310 to +350 mV. State Pollution Control Commission figures (unpublished) give a pH range of 7.4 to 8.9. The narrow range and lack of systematic variation between different areas of the lake suggest that it is improbable that either of these factors would limit *Zostera* within the lake.

Turbidity. Light availability has often been demonstrated as the factor setting the maximum depth to which seagrasses will grow (Backman and Barilotti, 1976). In Illawarra Lake *Zostera* occurred to a depth of 2 m in the entrance channel which was twice daily filled with low turbidity sea water. Throughout most of the eastern weed beds the outer limit was usually found at 1.5 to 1.8 m even though the sandy substrate continued beyond 2m in depth. In Griffins Bay and off the mouth of Mullett Creek, areas of fine sediment and high turbidity, the limit was inside the 1 m contour.

Turbidity values and the depth limit of *Zostera* growth for near Bevans Island, the eastern weed beds, and one site in Griffins Bay are given in Table 2. Values are given for turbidity of water on the outer edge of the seagrass beds and also within the seagrass bed. Turbidity measure can often change rapidly: in the narrow fringing seagrass beds on the western side of the lake, where sediments are generally finer, turbidity could change from 2 to 40 NTU (nephelometric turbidity units) within 10 min. of a strong southerly change acting upon the lake. In the highly turbid areas of Koong Burry Bay, Haywards Bay and Koona Bay, *Zostera* is dominated by *Gracilaria*, in Griffins Bay *Zostera* and *Gracilaria* are co-dominant and in the eastern weed beds *Gracilaria* is only of minor importance.

Water Movement. Zostera is reported to grow in regions with considerable water movement (Higginson, 1965). In Illawarra Lake it appeared to tolerate currents of several knots but to be less tolerant of strong wave action. Extensive colonies occurred on the margins of the entrance channel where they experienced strong tidal flow, and colonies in Mullet and Hooka creeks were not obviously disturbed by flood flows.

The role of wave action is difficult to assess. On exposed peninsulas like Wollingurry Point, Tallawarra Point, Kanahooka Point and Wollamai Point, or in

TABLE 2

Turbidity measure at various sites in Nephelometric Turbidity Units

	SITE							
	Near Bevans Island		Eastern Weed Beds				Griffins Bay	
Depth of weed growth	1.8 m		1.8 m		1.6 m		1.0 m	
Turbidity measure	at margin	in weed bed						
10.11.75	2.0	0.5	1.5	4.5	1.75	1.0	4.5	9.5
8. 1.76	1.5	3.5	1.0	2.0	2.0	2.0	3.0	3.5
17. 1.76	1.5	.75	1.5	1.5	2.0	2.0	2.5	1.5
29. 1.76	1.5	2.75	1.25	2.0	1.75	2.5	2.0	3.0
8. 2.76	3.0	1.25	1.5	2.5	2.0	1.5	2.75	3.0
14. 2.76	3.5	3.5	3.0	4.75	3.0	3.0	4.5	3.0
Mean	2.2	2.0	1.6	2.9	2.1	2.0	3.2	3.9

open bays like Tuggerah, Yallah and Moureendah Bays, strong wave action periodically deposited several centimetres of sediment; then later removed it exposing the underlying rock. *Zostera* was unable to produce more than minor colonies in these areas.

During 1975-76 the *Zostera* beds in the northern side of the training wall in Yallah Bay degenerated greatly. This occurred during a period of high wave action generated by persistent, strong easterly winds and considerable sediment disturbance was evident. Similar observations were made in the beds south of Wollingurry Creek.

Of the environmental factors examined water depth and turbidity appear to be the most important factors limiting the lower distribution of *Zostera* in the lake. There is no evidence that sediment type plays any major role as has been suggested in the case of submerged aquatic angiosperms in the Tuggerah Lakes system (Higginson, 1965). The minimum water depth limit for *Zostera* in Illawarra Lake varied widely. In Griffins Bay, along the eastern weed beds and west of Bevans Island *Zostera* was sparse in water less than 40 cm deep. These are areas of intensive feeding by ducks and swans. The ducks have been observed feeding on the shoots of *Zostera* and the swans on the rhizomes of both *Zostera* and *Ruppia*. In areas such as the Back Channel, swans were seldom observed and here *Zostera* grew well in 15 - 20 cm of water. In September 1976, when lake levels were low *Zostera* beds in Koonawarra Bay were exposed. During this period several hundred black ducks (*Anas superciliosa*) congregated in this area and over the next 3 days cropped the exposed *Zostera* and *Ruppia* to within 1 cm of the sediment surface.

II *Zostera* biomass in relation to environmental factors

Analysis of the transect biomass data with environmental data showed no overall correlation between *Zostera* biomass and the factors particle size, sediment pH or Eh, water pH or Eh, water temperature, and water or sediment total phosphorus. Despite the greater nutrient content of sediments in Griffins Bay, compared with those near Bevans Island, *Zostera* biomass at the latter location was significantly higher (1.5 - 3 times) than in Griffins Bay. There was however a distinct relationship between *Zostera* biomass and water depth, and hence light availability, Fig. 3a. Fig. 3b shows the growth of *Zostera* expressed as shoot length at the same sites. A similar relationship holds for total plant biomass and water depth. The differences between Bevans Island and Griffins Bay data are consistent with the notion that depth limits of *Zostera* at a given locality are a function of turbidity. The reduced biomass in water less than 40 cm is presumed to relate to waterfowl grazing pressure.

III Vegetative growth of *Zostera capricorni*

The seasonal growth cycle data for *Zostera* at selected localities during 1972-73 are shown in Fig. 4. The general pattern is similar with maximum leaf length occurring during summer and the minimum in winter. The onset of the new growth cycle occurred in August - September after shedding of the previous season's growth. Wood (1959a) reported that leaf loss follows flowering and in autumn *Zostera* flats may seem completely bare of leaves. In this study full leaf development was sometimes maintained until early spring by which time new leaf growth had commenced.

In 1973 rapid degeneration of *Zostera* beds occurred during February and March coincident with heavy rainfall. Similar declines in the standing crop followed heavy late summer and autumn rains in 1974 and 1976. In 1975 when rainfall was 40% less than average little decline occurred until the June - July floods. These changes were most marked in waters shallower than 0.6 m. This relationship between flood rains

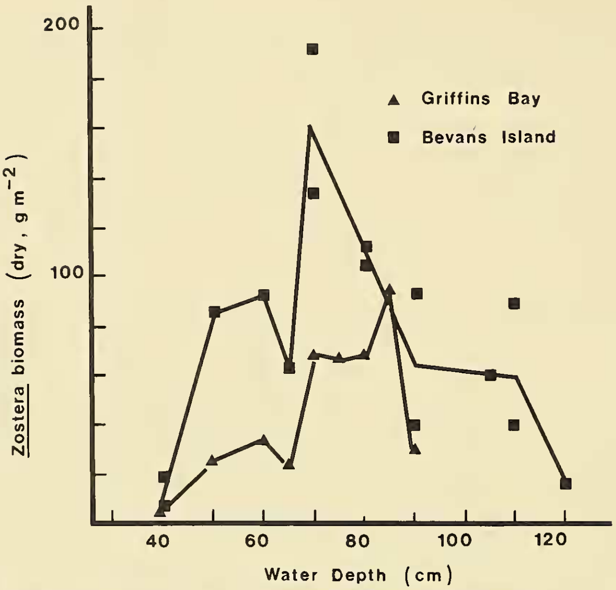

Fig. 3a. Zostera biomass (mean values) in relation to water depth — Bevans Island and Griffins Bay

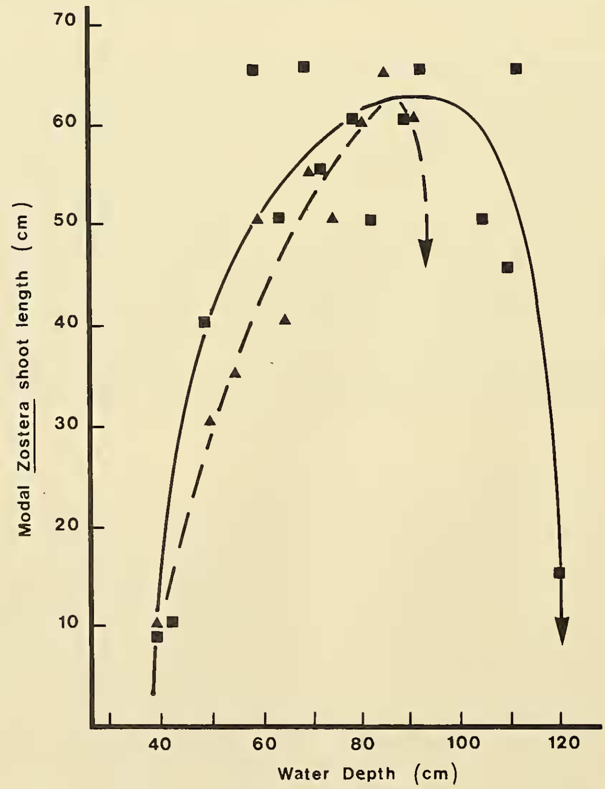

Fig. 3b. Zostera shoot length (mean values) in relation to water depth — Bevans Island and Griffins Bay, January 1976

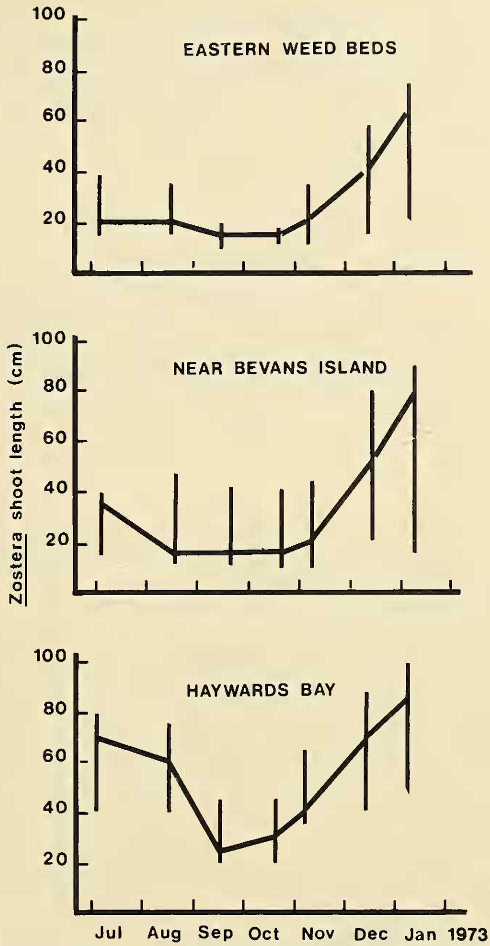

Fig. 4. Seasonal variation in shoot length of *Zostera capricorni* showing modal shoot length and range.

and leaf shedding was most marked in the eastern weed beds while colonies in sheltered localities such as Haywards and Koonawarra Bays or along the southern shore were barely affected. When the *Zostera* beds have their normal water cover, wave action is suppressed at the outer margin; however, during flooding the increased water depth allows for vigorous wave action throughout the beds, leading to extensive shedding of leaves. Associated lower salinities and increased turbidity may predispose *Zostera* towards leaf shedding but in the absence of mechanical agents it did not appear to arise from these causes alone.

IV Flowering and Seed Production

Flowering of *Zostera* in Illawarra Lake is variable both temporally and spatially. Immature flowering shoots were first observed in September and flowering sometimes extended through to August of the following year, with seed production from October to August. Generally peak flowering occurred in summer. Table 3 summarizes data for the season 1975-76. In that season flowering was abruptly terminated with

TABLE 3

Percentage of fertile shoots at three locations in summer 1975-76 based on 500 cm^2 composite sample

Site	October 1975			November			December			January 1976			February		
	Number of shoots examined	% fertile shoots	Number of seeds	Number of shoots examined	% fertile shoots	Number of seeds	Number of shoots examined	% fertile shoots	Number of seeds	Number of shoots examined	% fertile shoots	Number of seeds	Number of shoots examined	% fertile shoots	Number of seeds
Near Bevans Island	—	nil	—	992	4.1	57	650	10.6	89	579	13.9	112	406	2.2	7
Eastern Weed Beds	136	6.6	—	1295	7.5	34	679	12.2	61	516	17.2	83	250	1.2	2
Griffins Bay	—	nil	—	257	22.2	186	397	12.1	172	405	13.6	101	—	nil	—

shedding of flowering shoots after heavy January rains. The frequency of flowering shoots showed wide variation between years: in 1972-73 the frequency reached 34% near Cudgeree Island and in Haywards Bay.

The majority of flowers did not produce seed. The observed maximum of flowers producing seed was 10.9% in 1976 compared to less than 2.6% in 1973.

Germinating seeds were found in sieved sediment samples on only one occasion: near Bevans Island in July 1975. There was no evidence that *Zostera* was colonizing bare areas by seedlings. In dredged areas any subsequent recolonization occurred by rhizome invasion from adjacent areas. As found by Wood (1964), such recolonization is slow. Preliminary experiments with transplanting *Zostera* into the back channel near the Tallawarra Power Station and in Griffins Bay were successful when the plants were transplanted complete with relatively undisturbed sediments: washed rhizomes did not recolonize. These small transplants (size range 100 - 200 cm^2) were made in June - October 1975 and 3 years later those near the Tallawarra Power Station had expanded to cover some 10 times the original area. This expansion has taken place by marginal growth of the clump into formerly uncolonized sediments. Growth in Griffins Bay has been less pronounced though clumps are still growing.

Conclusion

Within Illawarra Lake *Zostera capricorni* showed a marked ecological tolerance. Within the range found in the lake the distribution and abundance of *Zostera* did not appear to be controlled by substrate factors (particle size, total phosphorus, pH, Eh) or water quality factors (salinity, total phosphorus. pH, Eh). Light availability as influenced by water depth and turbidity appeared to control the lowest depth to which the plant grows. Grazing by swans and ducks may have been significant in setting the upper limit.

Zostera showed a seasonal cycle with shedding of the previous season's growth promoted by wave action. Flowering was extensive, though patchy and seed production was observed over a lengthy period, October to August of the following year. Although seedlings were observed in the field there was no evidence to suggest that seedlings play a major role in propagation. Transplant experiments, using *Zostera* clumps in relatively undisturbed sediments, have been successful and clumps have been expanded by growth into previously uncolonized sediments.

ACKNOWLEDGEMENTS

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